King County Carbonate Fuel Cell Demonstration Project

Case Study of a 1-MW Fuel Cell Power Plant Fueled by Digester Gas

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Interim Report, February 2005

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PRODUCT DESCRIPTION

This case study documents the first-year demonstration experiences of a 1-MW carbonate fuel cell system operating on anaerobic digester gas at a wastewater treatment plant in King County, Washington. The case study is one of several fuel cell project case studies under research by the EPRI Distributed Energy Resources Program. This case study is designed to help utilities and other interested parties understand the early applications of fuel cell systems to help them in their resource planning efforts and to facilitate the cost-effective use of fuel cells in distributed power applications.

Results & Findings

Among the project's major accomplishments:

- The 1-MW carbonate fuel cell system was successfully fabricated, sited and installed at the wastewater treatment facility.
- The initial year of plant operation and testing was successful, as the plant achieved 1 MW of full power operation on anaerobic digester gas fuel without any de-rate in performance of the plant.

This interim report documents the installation, and first year of operation.

Objectives

The principal objectives of the project were to be adapt FuelCell Energy's carbonate fuel cell to use anaerobic digester gas from a wastewater treatment plant as primary fuel, and to demonstrate the technical and economic, performance, and emissions features of the fuel cell power system.

Applications, Values & Use

Carbonate fuel cell systems configured for combined-heat-and-power (CHP) operation can be adopted by and applied in a variety of end-use market segments where there is a need for continuous baseload power and waste heat in the form of steam or hot water. Early applications are being employed at locations that offer "opportunity fuels," such as anaerobic digester gas at wastewater treatment plants.

EPRI Perspective

EPRI's DER Program provides objective technical and testing assessments of emerging distributed power options including advanced engines, microturbines, fuel cells, small energy storage systems and Stirling engines. Utility business risks and opportunities for fuel cell technologies have been areas of interest among program participants. This project is one of several technical evaluations EPRI's program is conducting in the fuel cell systems area. EPRI's program will continue to monitor the testing of this fuel cell system in 2005.

Approach

EPRI entered into a collaborative agreement with the King County Department of Natural Resources and Parks, Wastewater Treatment Division, to assess the demonstration of fuel cell power systems developed by FuelCell Energy. EPRI also obtained additional project information from FuelCell Energy to include in this report.

Keywords

Fuel cells

Carbonate fuel cells

Anaerobic digester gas

King County

FuelCell Energy

Distributed generation

Distributed energy resources

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We would also like to acknowledge the efforts of Eleanor Allen and Jaimie Hennessy of CH2MHill and David Hennessy of FuelCell Energy, who also helped in data collection, input, and review of this report. In addition, Hans Maru of FuelCell Energy provided key project information, guidance, and draft review.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1
INTRODUCTION

1.1 Project Summary

The Department of Natural Resources and Parks of King County, Washington, has undertaken a two-year demonstration project of a 1-MW carbonate fuel cell power plant fueled by anaerobic digester gas. The project, being carried out with the support and cooperation of the U.S. Environmental Protection Agency (EPA) and fuel cell manufacturer FuelCell Energy (FCE), is the largest such plant in the world. CH2M Hill and Brown and Caldwell are assisting King County in site utility and design; coordinating and managing site and equipment interfaces; providing day-to-day coordination between King County and FCE; monitoring and reporting project status; providing assistance during construction, start-up, testing, and operation; and analyzing and reporting the results of the demonstration project.

The King County Fuel Cell Demonstration Project began in 1998, with the overall objective of siting a carbonate fuel cell power plant at the County's wastewater treatment plant in Renton, Washington. The wastewater treatment process produces solids that are typically treated via anaerobic digestion, a process that generates large quantities of anaerobic digester gas (ADG) comprising approximately 60% methane (CH_4) and 40% carbon dioxide (CO_2). Small ADG plants typically burn the gas in a flare. Larger plants tend to utilize the gases on site for heat and/or power; a handful remove the CO_2 in order to sell the remaining gas. Using the gas to fuel a fuel cell can make more efficient use of gas resources while generating electricity.

FCE was selected in 2000 to supply a 1-MW fuel cell power plant to King County. Project objectives are to demonstrate the carbonate fuel cell and anaerobic digester gas fuel system in a grid-connected configuration. The plant operates in parallel with the grid, although all power generated is consumed by the wastewater facility so that no power is exported. The carbonate fuel cell is installed in a combined-heat-and-power (CHP) configuration in which heat from the fuel cell exhaust gas is used in the plant heat loop for digester heating. The demonstration project is intended to verify the electrical efficiency capabilities of a carbonate fuel cell, demonstrate unattended and quiet operation, and produce an environmentally benign emissions profile.

Facility construction began in 2002 and was completed in January 2004. This report summarizes the project's history, objectives, and the initial results of plant operation to date.

Carbonate Fuel Cell Technology[1]

Fuel cells electrochemically combine hydrogen with oxygen to produce electricity, heat, and water. The direct electrochemical conversion of hydrogen to dc power is much more efficient than if it were combusted. All fuel cells have three key component parts: an anode, a cathode, and an electrolyte. There are several types of fuel cells, characterized by the composition of the electrolyte, supporting structure, and electrochemical process involved.

Carbonate salts serve as the electrolyte in a carbonate fuel cell, which is among the most energy-efficient fuel cell technologies. Operating at a temperature of 650°C (about 1,200°F), the salts melt and conduct carbonate ions (CO_3) from the cathode to the anode. At the anode, hydrogen reacts with the ions to produce water, carbon dioxide, and electrons. Electrons travel through an external circuit and return to the cathode. There, oxygen from air and carbon dioxide recycled from the anode react with the electrons to form CO_3 ions that replenish the electrolyte and transfer current through the fuel cell (Figure 1-1).

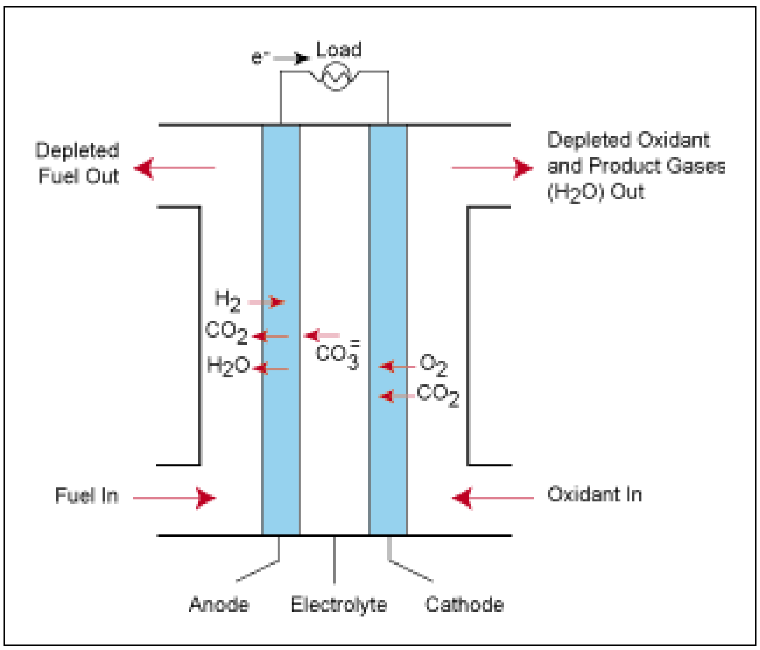

Figure 1-1
Electrochemical Reactions within a Carbonate Fuel Cell

High-temperature carbonate fuel cells can directly convert hydrogen from a variety of fuels using either an internal or external reformer. Because they can also directly reform carbon monoxide to hydrogen at the anode, they are not prone to carbon monoxide “poisoning,” which is problematic for lower temperature fuel cells such as polymer electrolyte membrane (PEM)-type systems.

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[1] See the following EPRI reports for a more detailed technical assessment of carbonate fuel cell technology:
Design and Testing of a Landfill Gas Cleanup System for Carbonate Fuel Cell Power Plants, EPRI, Palo Alto, CA: 1997. TR-108043-V1 and –V2.
Development and Demonstration of a 250-kW Molten Carbonate Fuel Cell Power Plant: Miramar Naval Air Station, EPRI, Palo Alto, CA: 1997. TR-109083.
Santa Clara 2-MW Fuel Cell Demonstration: Power Plant Test Report, EPRI, Palo Alto, CA: 1997. TR-108252.

Carbonate fuel cells are uniquely suited for digester gas applications because no significant derating of power output is expected due to the dilute methane content of digester gas. The CO_2 component in digester gas is also beneficial for cathode reaction.

Carbonate fuel cells have the potential to exhibit electrical efficiency in excess of 50% and overall energy efficiency as much as 80% when the waste heat is recovered in CHP applications. Current carbonate fuel cell demonstration units are in the 250-kW scale. In addition to the 1-MW power plant at King County, a 2-MW power plant demonstration is also planned for coal gas application.

About FuelCell Energy

FuelCell Energy, Inc., based in Danbury, Connecticut, is a world leader in the development and manufacture of high-temperature fuel cells for clean electric power generation. The company has developed commercial distribution alliances for its carbonate Direct FuelCell (DFC) products with companies such as Caterpillar, PPL Energy Plus, Alliance Power, Chevron Energy Solutions and LOGANEnergy in the United States; Marubeni Corporation in Asia; MTU CFC Solutions in Europe; and Enbridge Inc. in Canada. FuelCell Energy developed its patented Direct FuelCell technology for stationary power plants with the U.S. Department of Energy through its Office of Fossil Energy's National Energy Technology Laboratory.

FuelCell Energy is also developing next-generation high-temperature fuel cell products—such as a diesel-fueled marine Ship Service Fuel Cell, a combined-cycle DFC/Turbine® power plant and solid oxide fuel cells—for applications up to 100 kW through its partnership with Versa Power Systems. More information is available at www.fuelcellenergy.com.

About Direct FuelCells®

FuelCell Energy's Direct FuelCells efficiently generate clean electricity at distributed customer locations, including municipal/industrial wastewater treatment facilities, telecommunications/data centers, hotels, universities, manufacturing, hospitals, prisons, federal facilities and grid support. Direct FuelCells convert readily available fuels, such as natural gas or waste gas, to electrical power with greater efficiency than any competing technology of comparable size, including other fuel cells. This high-efficiency technology generates more electric power from less fuel and has the lowest emissions of any fossil based electric generating technology because the fuel is not burned. DFC power plants can be sited at or near users, and the heat byproduct can be used for cogeneration applications such as district heating, hot water or absorption chilling for air conditioning. Depending upon location, application and load size, the company's DFC power plants in a cogeneration configuration can achieve an overall energy efficiency of between 70% and 80%. The sub-megawatt fuel cell power plant is a collaborative effort using Direct FuelCell® technology of FuelCell Energy and the Hot Module® balance-of-plant design of MTU CFC Solutions, GmbH, a subsidiary of DaimlerChrysler.

About King County

Partially located along Puget Sound in Washington State, King County covers more than 2,200 square miles and has a population exceeding 1.7 million, making it the 12th most populous county in the United States. The Wastewater Treatment Division of the King County Department of Natural Resources and Parks protects public health and ensures water quality in 18 cities, 16 local sewer agencies, and more than 1.4 million residents in King, Snohomish, and Pierce counties. King County established the 95-acre South Treatment Plant in Renton, Washington—the site of the carbonate fuel cell demonstration—in 1965. In addition to treatment operations, the plant site includes facilities for handling biosolids and testing alternative treatment technologies.

About CH2M Hill

Founded in 1946 in Corvalis, Oregon, CH2M Hill is an employee-owned, multinational firm providing engineering, construction, operations, and related services to public and private clients in numerous industries on six continents. In 2003, the company had approximately 14,400 employees and gross revenues of more than $2.6 billion.

About Brown and Caldwell

A full-service environmental engineering firm, Brown and Caldwell has been designing and implementing customized solutions to complex environmental problems for more than 55 years. The company is headquartered in Walnut Creek, California, and has more than 1,000 employees in 40 offices working with municipalities, government agencies and private industry across the country.

2
PROJECT ORGANIZATION AND IMPLEMENTATION

2.1 Project Objectives

Increasing energy costs, more stringent air emission regulations, and an interest in exploring emerging energy technologies, prompted King County to search for new and innovative ways to provide electricity for its wastewater treatment plants. Fuel cells, which run on hydrogen or reformed hydrocarbon fuels, including anaerobic digester gas, are electrochemical devices that produce electricity with few or no emissions. When successful, the King County Fuel Cell Demonstration Project could pave the way for future full-scale fuel cell projects at similar wastewater treatment plants worldwide.

In addition to the reasons listed above, this site was selected for the project because it has two different gas supplies on site (anaerobic digester gas and scrubbed anaerobic digester gas or "pipeline quality" natural gas) and available space near the digesters.

The objectives of this project are to demonstrate that:

- FCE's carbonate fuel cell can be adapted to use anaerobic digester gas from a wastewater treatment plant as fuel.
- A nominal plant output target of 1 MW net ac power can be achieved using digester gas.
- Other municipal wastewater treatment plants throughout the world could use similar fuel cell power systems to produce electricity.
- Such fuel cell systems can operate reliably over the course of the project timeframe, with fuel cell stacks replaced every two to five years.

Specific project goals and performance metrics include:

- Producing electric and thermal energy from natural gas, scrubbed anaerobic digester gas, and unscrubbed anaerobic digester gas.
- Demonstrating net electrical efficiencies of 45% [net of the additional energy required to treat the raw digester gas].
- Producing 15,000 MWh gross power over the two-year evaluation period.
- Exhibiting the ability to run at 85% of power for two years.
- Exhibiting the ability to operate on a continuous basis, with an availability of greater than 80%.

- Limiting downtime for maintenance and troubleshooting to less than 20 hours per week (and determining the real-world frequency and duration of downtime).
- Demonstrating the ability to manage the system remotely.
- Producing minimal air emissions.
- Successfully recovering heat, with the goal of 1.4 million Btu/hr.
- Meeting noise design criteria of 60 dBA at 100 feet from the fuel cell pad.

2.2 Contractual Relationships

The project was initially conceived in 1996, following a site-specific fuel cell feasibility study and the establishment of an initial partnership agreement with fuel cell manufacturer MC Power. King County agreed to pursue the project if outside local or federal funding could be secured. Although the King County-MC Power team received a $12.5 million U.S. EPA grant to demonstrate a fuel cell project, MC Power subsequently lost its U.S. DOE funding and went out of business. King County remained dedicated to the idea and issued a request for proposals seeking quotes from other fuel cell vendors, from among which FCE's response was selected based on the company's compelling commitment to financially support the project. Current contractual relationships are as follows:

- King County is the plant owner, operator, and provider of the host site. County personnel also managed site construction and installation activities.
- Hawk Mechanical is a Washington contractor to King County involved with site construction and FCE's equipment installation.
- Engineering firms CH2M Hill and Brown and Caldwell are consultants to King County, responsible for engineering and program management services.
- FCE is under contract to King County to provide, deliver and start up the complete fuel cell power plant as well as the equipment for digester gas cleanup. FCE also contributed a significant cost share to help fund the project. In addition, FCE agreed to train on-site staff to operate and maintain the fuel cell system. The training consists of classroom as well as hands-on instruction. The U.S. EPA is a major project sponsor.FCE and King County negotiated a separate agreement covering maintenance, service, and stack replacement.

2.3 Funding and Budget

Total plant cost to date is approximately $22.8 million. Of that total, $12.5 million was provided through a grant from the U.S. EPA. FCE's contract for the project totaled $18.96 million, of which half, or $9.48 million, was cost-shared by FCE. King County is providing fuel in addition to site labor and operators as in-kind support. Other King County costs and provisions include:

- Installation and construction services provided by Hawk Mechanical: $1.8 million.
- Program management and monitoring services by CH2M Hill: $1.3 million.
- WTD expenditures for staff and miscellaneous: $230,000.

- MC Power expenditures: $473,000.

2.4 Permitting

Few permits were required for the project. Due to the ultra-clean characteristics of fuel cell emissions, the project was exempted from air permit requirements by the Puget Sound Clean Air Agency. A building permit and a conditional use permit were obtained from the City of Renton.

Considerable effort was spent inspecting electrical work on the fuel fell equipment skids due to the uniqueness of the equipment and their application. A third-party electrical inspector was hired to help facilitate inspection requirements between the City of Renton and King County. See further discussion in Chapter 5.

An interconnect agreement was executed with Puget Sound Energy. This is described in detail in Chapter 5.

2.5 Project Staff and Peer Review Team

Appendix B provides a roster of project staff, their affiliations, and their responsibilities. In addition, the King County Fuel Cell Demonstration Project is guided by a Peer Review Team that consists of industry experts who meet semi-annually to review data and test results, and advise on any changes to the testing program. To facilitate operations and keep all stakeholders apprised of the project's status, King County has scheduled five Peer Review Team meetings between November 2003 and May 2006.

3
PROJECT DESCRIPTION

3.1 South Treatment Plant Overview

The South Treatment Plant, located in Renton, Washington, was constructed in 1965 and has experienced numerous upgrades and expansions. The average capacity of the treatment plant is 115 million gallons per day (MGD). Effluent pumps that move treated wastewater leaving the plant have been upgraded to handle a maximum of 325 MGD. The 95-acre facility includes facilities for biosolids handling, water reuse, and testing alternative treatment technology. Figure 3-1 is an aerial photo of the wastewater treatment plant.

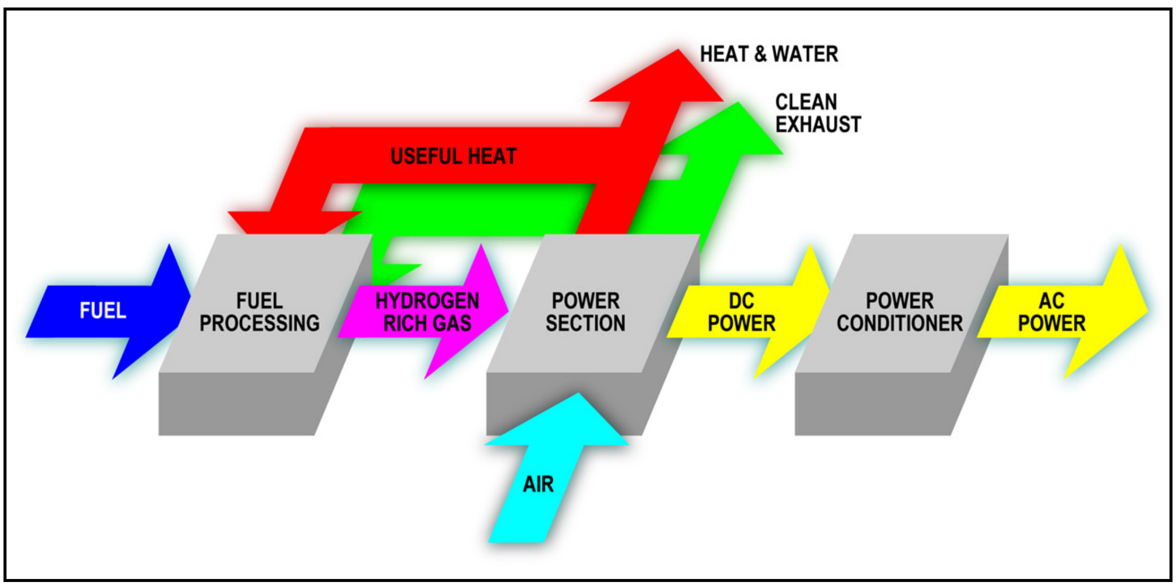
Figure 3-1
Aerial Photo of South Treatment Plant

Currently, the plant treats an average wet weather flow of approximately 70 MGD to full secondary treatment using activated sludge. Secondary effluent is discharged through a deep ocean outfall. A small portion of the secondary effluent receives additional treatment to become State of Washington Class A reclaimed water. Solids are cothickened and stabilized using mesophilic anaerobic digestion. The dewatered Class B biosolids are applied to land in eastern Washington and silviculture in western Washington; in addition, a portion is composted.

Anaerobic digester gas (ADG) for the fuel cell stacks is produced in five digester tanks that are located approximately 1,000 feet (300 m) from the fuel cell power plant. These tanks feed gas through large pipes to a header, which feeds into a gas scrubbing system nearly adjacent to the tanks. The gas that is scrubbed to remove carbon dioxide and hydrogen sulfide is sold to Puget Sound Energy (PSE) as pipeline-quality natural gas. A portion of this biogas is now diverted prior to the PSE scrubbers and sent to the fuel cell power plant. King County plumbed a tap near the flare and routed the gas another 500 feet to the demonstration site. A turbine cogeneration facility is currently under construction at the South Treatment Plant which, when operating, will consume the remaining 3 MW of scrubbed digester gas and up to 5 MW of natural gas.

3.2 Fuel Cell Demonstration Project Overview

The King County Fuel Cell Demonstration Project is scaled to produce 1 MW of electricity. Waste heat from the fuel cell power plant is integrated into the wastewater treatment system's existing plant heat distribution system, further enhancing efficiency. The carbonate fuel cell plant is adapted from FCE's standard natural-gas-fueled Direct FuelCell (DFC) module, modified simply by adding supplemental equipment and controls necessary to pre-treat and handle unscrubbed digester gas. Power plant components were sized to permit power generation up to 1.5 MW if an uprate becomes available in the future. Figure 3-2 provides a process flow diagram of the system.



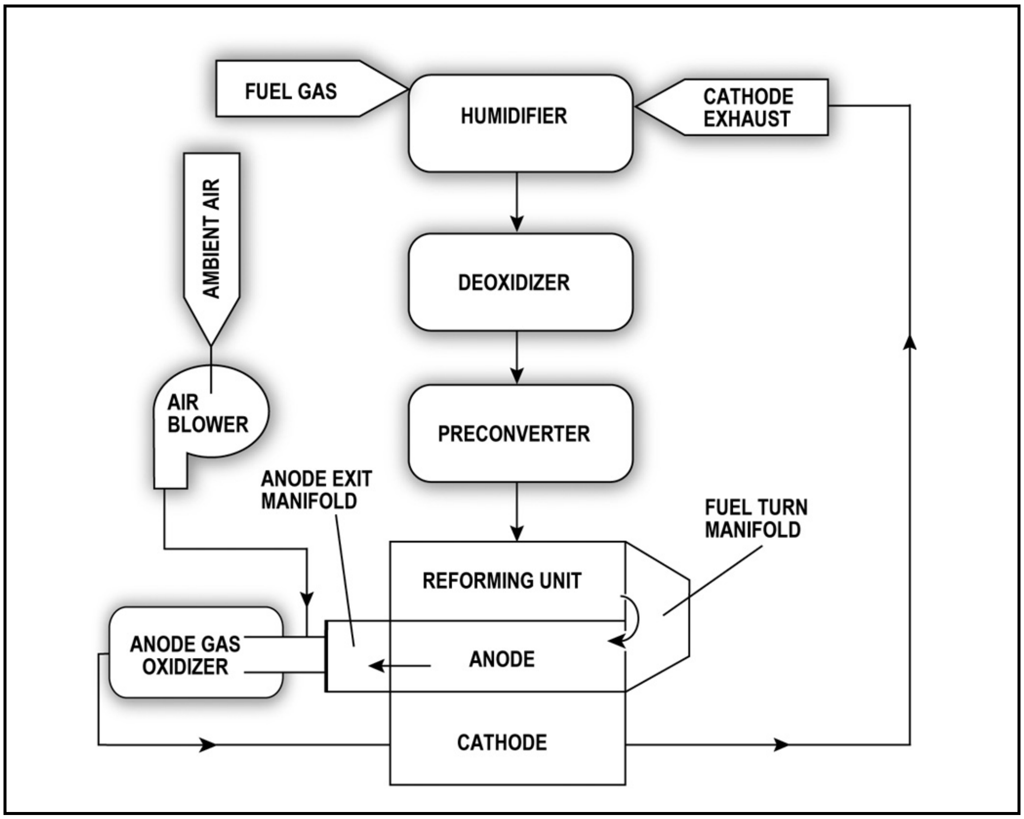
(Source: FuelCell Energy)

Figure 3-2
Fuel Cell Process Flow Diagram

The fuel cell system contains the following components, illustrated schematically in Figure 3-3 and described in greater detail below:

- Fuel cell stack module
- Electrical Balance of Plant (EBOP)

- Natural gas conditioning
- Digester gas treatment
- Anode fuel gas treatment
- Anode exhaust gas treatment
- Oxidant supply
- Cathode exhaust gas treatment



(Source: FuelCell Energy)

Figure 3-3
Fuel Cell System Components

In addition, the system includes ancillary components such as:

- Heat recovery system
- Water treatment system
- Instrument air system
- Nitrogen gas supply system (Nitrogen gas is used to purge the plant when there is a shut down)

Figure 3-4 provides a block diagram for the fuel cell plant's inputs, outputs and processes, many of which are described in further detail below.

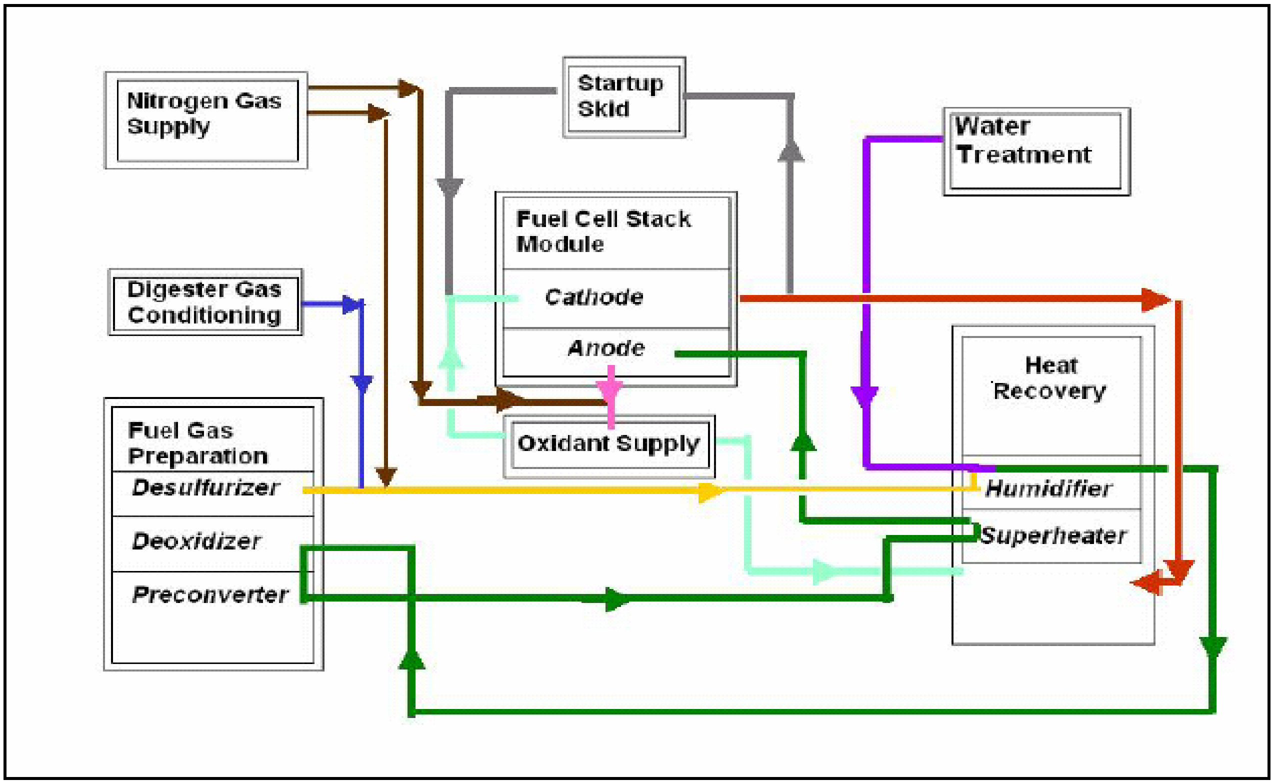


Figure 3-4
Plant Block Diagram

3.3 Controls and Instrumentation

The following controls and instrumentation govern the proper operation and control of the fuel cell module:

Stack Module Temperature Controls

Overall temperature control of the fuel cell stack module is achieved via the oxidant (air) supply system and the internal reforming of the fuel supply (methane). Both the temperature and flow of oxidant gas from the oxidizer is directly controlled to meet the required operating conditions. During plant heat-up and plant cool-down, a temperature ramp generator provides temperature set points for the oxidizer effluent/cathode inlet gas. During power generation and hot standby mode, oxidant airflow is controlled to maintain stack temperature between preset inlet and outlet limits to optimize the overall module temperature.

The temperature of the anode fuel gas entering the fuel cell stack module is not controlled, but is dependent on the temperature and flow of cathode exhaust gas through the fuel superheater. The resultant temperature is approximately 1000°F. Heat losses from the anode fuel gas line are minimal due to the close coupling of the fuel cell stack module and heat recovery unit.

Stack Module Pressure Controls

The fuel cell stack module contains four stack assemblies. Pressures within the fuel cell stack module are not controlled, but are the result of the accumulated system pressure drops through the plant. The pressure difference between the anode inlet/outlet and the cathode inlet is monitored for indications of any cross-cell leakage.

Fuel Cell Stack Voltage Controls

The fuel cell stack module includes instrumentation for monitoring the voltages of individual fuel cells and voltages generated across groups of fuel cells within the individual stacks.

Control of Fuel Utilization

During power generation, the fuel gas flow rate and current drawn from the fuel cell stack module are carefully coordinated. Inherent to the proper operation of a fuel cell is maintaining a fuel concentration at the anode during operation. The amount of power (current) that can be drawn from the fuel cell stack module is directly dependent upon the *theoretical hydrogen content* (TH_2) of the fuel gas feed stream. TH_2 is defined as the maximum amount of hydrogen that can be generated from the fuel gas assuming 100% completion of the hydrocarbon reforming and shift reactions. The fraction of the fuel gas stream's TH_2 that is allowed to react within the fuel cell anodes to generate electric power is the *fuel utilization* (U_f). Significant deviation between target and actual fuel utilization triggers an alarm and control response.

DC Power Controls

The electrical outputs of the four fuel cell stacks are connected in parallel to a common dc bus. The positive (cathode) terminal is resistance grounded. The stacks are electrically isolated by blocking diodes. The dc current is sent to the inverter, which is connected to the 480 Vac power system via step-up isolation transformers.

Electrical Balance of Plant (EBOP)

The EBOP is an outdoor, non-walk-in enclosure containing the power conditioning system (PCS), dc power fuses, ac grounding circuit, dc isolation diodes, ac utility interconnection circuit breaker and protective relaying, distributed control system (DCS), and low-voltage distribution equipment.

The PCS was manufactured by ABB and converts dc power from the fuel cell stack modules to ac power for export and to the plant's auxiliary loads bus. The PCS inverters employ pulse width modulation (PWM) of the power semiconductors to provide ac electric power at

480 volt/three-phase/60 Hz that meets the requirements of IEEE 519. The power is then sent to the treatment plant.

3.4 Fuel

Anaerobic digesters treat wastewater solids by maintaining a population of anaerobic bacteria in a heated environment. The bacteria break down organic material in the solids. Anaerobic digester gas (ADG) is the by-product of this treatment process and comprises methane (approximately 60% to 70%), carbon dioxide (approximately 30% to 40%) and other trace elements.

Typical ADG processes yield approximately 10,700 cubic feet of digester gas for each million gallons per day (MGD) of wastewater treated. A wastewater treatment plant equipped with anaerobic digesters and with influent flows of approximately 30 MGD will produce sufficient digester gas to generate 1 MW of electricity from a high-temperature fuel cell such as a carbonate fuel cell. In the United States, there are approximately 400 wastewater treatment plants that could generate electricity using fuel cell power plants. Since scrubbing equipment can be expensive, King County's South Plant is one of only a few treatment plants that scrub and sell their digester gas.

Gas Supply and Treatment

Natural gas (either from the local utility or scrubbed digester gas from the South Plant itself) normally passes through a custody transfer station comprising a filter, pressure regulator, and flow meter at the plant boundary limit. It enters the plant through a manual isolation valve and pressure control valve, which lets it down to about 15 psig. This pressure control is necessary to maintain a nearly constant pressure in the downstream cold gas desulfurizers, whose performance is impacted by system pressure.

The natural gas is then fed to a natural gas heater, which heats incoming gas to 60°F whenever required to maintain performance in the downstream cold gas desulfurizers. Natural gas is then routed to the cold gas desulfurizers, which remove sulfur compounds (mostly H_2S, but also trace amounts of CS_2, SO_2, mercaptans, sulfides, disulfides, and thiophenes) from the natural gas to concentrations less than 0.1 ppmv. The quantity of sulfur compounds that can be adsorbed on the beds is dependent upon the bed operating pressure and temperature as well as the inlet gas flow and composition. Each of the beds has sufficient capacity to desulfurize feed gas at rated conditions for 27 weeks of operation. The two cold gas desulfurizers are normally operated in series. A third cold gas desulfurizer is in the process of being added upstream of the FCE plant and in series with the original cold gas desulfurizers. The third desulfurizer vessel contains copper and aluminum oxide media that removes carbonyl sulfide (COS) from the natural gas that is supplied by Puget Sound Energy from off-site.

Digester Gas Conditioning System

King County's South Plant can provide both scrubbed and raw digester gas to the fuel cell system. Table 3-1 summarizes the composition of South Plant digester gas before it enters the gas conditioning system.

Table 3-1
King County Digester Gas Analysis

Composition	Range/Limits[1]	Typical
Methane (vol%)	57-61	60.5
CO_2 (vol%)	36-38	37.7
N_2 (vol%)	0.6-1.1	1.0
O_2 (vol%)	0.2-1.4	1.0
Ethane (ppmv)	35-51	40
Propane (ppmv)	<2	1
Butanes (ppmv)	<1.3	0.7
Pentanes (ppmv)	2.9-15	7
Benzene (ppbv)	20-40	30
Toluene (ppbv)	20-800	400
Sulfur:		
H_2S (ppmv)	39-200	150
$CS_2 + SO_2$ (ppbv)	<50	25
Heating Value:		
LHV (Btu/scf)		552
HHV (Btu/scf)		613

[1] Values given during normal operation.

The fuel cell's fuel conditioning system treats raw digester gas to make it suitable for use by the fuel cell. The conditioning system performs the following functions:

- Receives unscrubbed digester gas and compresses it to about 26 psig. The compression system skid includes the digester gas feed knock-out (KO) drum at the compressor suction. The digester gas aftercooler and digester gas discharge KO drum are provided on the compressor discharge. Downstream of the compressor skid, a high-efficiency oil filter reduces entrained oil in the ADG to 0.5 ppmw. Condensed liquids removed from the ADG are returned to the water treatment plant.
- Treats the cooled compressed ADG by passing it through SulfaTreat vessel for bulk hydrogen sulfide (H_2S) removal (to less than 10 ppmv), and then through two activated carbon polishers in series for trace sulfur compound and siloxane removal. Remaining sulfur compounds (mostly H_2S) are removed to less than 0.1 ppmv. The SulfaTreat bed has sufficient capacity to desulfurize the feed gas at rated conditions for 40 weeks of operation.

Each of the polisher beds has sufficient capacity to treat digester gas at rated conditions for 27 weeks of operation.

Anode Fuel Gas Treatment Controls

The anode fuel gas treatment portion of the fuel gas preparation system performs the following functions:

- Simultaneously humidifies and superheats the fuel gas in the fuel humidifier—part of the heat recovery unit (HRU)—to meet the temperature requirements of the downstream fuel treatment equipment using waste heat recovered from the fuel cell cathode exhaust.
- Treats the preheated fuel gas in fuel deoxidizer to remove oxygen, which is required to protect the pre-converter and fuel cell catalysts from oxidation. Oxygen is normally present in digester gas and natural gas that has been supplemented with peak-shave gas, and may be present in small amounts in natural gas. The gas heats up as it passes through the fuel deoxidizer because the oxygen-removal reactions are exothermic.
- Partially reforms the deoxidized fuel gas in the preconverter to eliminate C_2+ hydrocarbons and generate an initial hydrogen gas concentration. High molecular weight hydrocarbons (C_2+) must be reformed away to avoid carbon deposition in the fuel cell stacks at elevated temperatures. A small hydrogen gas partial pressure is established in the gas to maintain a reducing environment. The gas cools as it passes through the preconverter due to the endothermic reforming reactions.
- Heats the preconverter effluent gas in the fuel superheater (part of the HRU) to the temperature required by the fuel cells using waste heat recovered from the fuel cell cathode exhaust. The resultant anode fuel gas is fed to fuel cell stack module.

The desulfurized fuel gas/vaporized water mixture exiting the fuel humidifier must be treated in the deoxidizer and preconverter before it can be fed to the fuel cell stack anodes.

Anode Fuel Gas Supply Controls

Gas exiting the fuel superheater is routed to the anode fuel gas inlet of the fuel cell stack module through an electrically heat-traced pipe. The electric heat tracing is designed for high-temperature operation to limit anode fuel gas heat loss, and should ensure that the gas temperature always remains at the required temperature.

Anode Exhaust Gas

Anode exhaust gas from the fuel cell stack module is routed to the oxidizer, where the remaining fuel components in the low-BTU anode gas are catalytically oxidized to generate CO_2, water vapor, and heat.

Oxidant Supply System

The oxidant supply system performs the following functions:

- Compresses ambient air to be used as cathode oxidant.
- Mixes compressed air with anode exhaust gas from the fuel cell stack module and catalytically oxidizes the fuel components in the anode exhaust gas.
- Generates cathode oxidant gas at the flow rate and temperature required for various plant operating modes.
- Delivers hot oxidant gas to the cathode side of the fuel cell stack module.

The oxidant supply system integrates the operation of the fuel cell anodes and cathodes during power generation by:

- Utilizing the residual fuel energy and sensible heat in the anode exhaust gas to heat air to the required oxidant gas temperature, and
- Recirculating carbon dioxide generated in the fuel cell anodes to the fuel cell cathodes to support the cathode reactions.

The oxidant supply system consists of an air blower and thermal/catalytic oxidizer.

Air Blower

The air blower is a rotary air compressor with a variable-speed drive to provide a wider range of operation. The blower provides up to 5,000 scfm of oxidant air to the oxidizer and to the oxidizer’s sight glasses and flame detector cooling air system.

Oxidizer

The oxidizer consists of a natural gas burner and fuel piping train, a thermal reactor, and a catalytic reactor. Oxidizer controls are designed to meet the following three functional requirements:

- Burner Fuel/Air Controls: Controls burner operation including firing rate, air-to-fuel ratio, burner/pilot sequencing, and flame safety systems.
- Total Airflow Controls: Ensures that total airflow meets the requirements of the fuel cell stack module.
- Oxidation Catalyst Temperature Controls: Ensures that the oxidation catalyst operating temperature is kept high enough for proper catalyst operation.

Cathode Exhaust Gas

Cathode exhaust gas from the fuel cell stack module is routed to the "shell" side of the heat recovery unit, where it is used as the heat source for the fuel superheater and fuel humidifier.

3.5 Site Configuration

Figure 3-5 illustrates the fuel cell facility layout.

Figure 3-5
Fuel Cell Demonstration Project Layout

Figures 3-6 through 3-9 provide additional photos, taken in April 2004, of the fuel cell demonstration project site. Equipment may be compared to the diagram in Figure 3-5. Figure 3-10 is an overview of the site. All photos are provided by King County.

Figure 3-6
The center rectangular enclosure is the Electrical Balance of Plant (EBOP) skid, with the cylindrical vessel containing the fuel cell stacks visible to the right.

Figure 3-7
View looking south at the gas/air processing skid, where natural gas or digester gas and water are humidified and air is preheated and directed to the fuel cell stacks.

Figure 3-8
Heat recovery equipment that captures hot exhaust gas to heat water in a boiler that is then piped back to treatment plant digesters.

Figure 3-9
Three tall cylinders at right are activated carbon (left and center) and SulfaTreat (right) vessels used to scrub digester gas.

Figure 3-10
King County DFC1500 Fuel Cell Power Plant

3.6 Electrical Interconnection

The fuel cell power plant is rated at 1.0 MW net output at 480Vac. The output is tied to a transformer to step-up the voltage to 13,090V at the plant's main substation. The output of the fuel cell uses a 3,200-amp breaker as the tie breaker in conjunction with protective relays to provide the interconnection protection required. The protection includes over/under-voltage and frequency, over-current phase and ground, directional ground fault, and sync-check. The protection package matches Puget Sound Energy's (PSE's) interconnection protection requirements.

3.7 Host Site Heat and Power Load

The power load of the treatment plant is approximately 7 MW. The South Treatment Plant produces sufficient gas to generate approximately 4 MW of electricity. Before the fuel cell was on line, all the gas was scrubbed and sold to PSE. Now, the equivalent of 1 MW of gas is used by the fuel cell. When the planned cogeneration turbines are installed in 2005, they will use the remaining 3 MW of scrubbed gas and no gas will be sold to PSE. Since the power demand of the treatment plant exceeds the fuel cell capacity, no power is exported to PSE.

The heat recovery system for the exhaust is sized for 1.7 million MMBtu/hr of waste heat. At 45% electrical efficiency and rated heat recovery (1.7MMBtu/hr), the net thermal efficiency of the plant will be approximately 67.5%, with waste heat returned to the digester heat loop.

4

OPERATING HISTORY AND INITIAL RESULTS

4.1 Key Events

The King County Fuel Cell Demonstration Project was constructed within a 12-month period following its groundbreaking in April 2003. Table 4-1 summarizes noteworthy events in the project's history through December 31, 2004 and specifically during start-up (April through early September 2004).

4.2 Demonstration Test Results

Since the King County Fuel Cell Project is a demonstration project, with limited hours of operation to date, there is limited operating information available to report. Data from operations are being tracked by King County and will be reported to project participants and peer review participants by King County. Appendix A provides a detailed list of monitoring plan, goals, and performance factors that will be examined over the course of the project.

Digester Gas Treatment System

The digester gas treatment system adequately removed the target contaminants during 2004. It did not require removal for service or replacement. Samples taken on December 7, 2004 indicate the beds will last at least through the first quarter of 2005.

Natural Gas Supply System

In April 2004, a shutdown of the digester gas scrubbing operation at the King County treatment system caused a total loss of fuel to the fuel cell power plant. The project was delayed for approximately two months while King County worked with Puget Sound Energy (PSE) to provide a backup source of pipeline quality natural gas to the fuel cell. During the course of installing piping modifications to facilitate a gas supply, additional modification to one of the FCE cold gas desulfurizers was required. This included installing special media capable of removing the amounts of carbonyl sulfide (COS) that exist in the PSE supplied natural gas. In addition, King County expects to have a COS removal vessel in place and operating in early 2005.

King County Scrubbed Digester Gas Treatment System

When the King County digester gas scrubber exhaust gas does not meet the specified PSE Btu content, scrubbed gas is diverted back to the main ADG header and ultimately to the flares when sufficient pressure has been reached. The divert events cause the methane content of the unscrubbed digester gas in the ADG header to increase abruptly. This rapid increase (outside the limits of the FCE digester gas specifications) is not easily accommodated by the fuel cell, as the change in methane content requires a change in gas flow to supply the same amount of fuel to the fuel cell. Despite the discovery of this divert scheme late in the project, FCE developed and implemented logic that provides for automatic fuel switching, at power, from digester gas to natural gas when a change to digester gas composition is expected. This logic has been in place since mid-December 2004 and will result in greater operating hours and higher availability numbers.

Fuel Cell Stack

No problems have been recorded with the fuel cell stack. As expected, there was no derating of power output due to dilute methane content of digester gas.

Heat Recovery System

The heat recovery system was not in operation during the period covered in this report. Modifications to the heat recovery system are required but are unrelated to the FCE power plant. The heat recovery system is expected to be in operation by the end of the first quarter of 2005.

Electrical Balance of Plant (EBOP)

No problems have been recorded with the EBOP.

Availability

Out of a total possible 1,872 hours between June 14 and August 31, 2004, King County reported 122.5 hours of forced outage time, or an availability of 93.5%. The 122.5 hours is attributable to two types of events:

- A cumulative 73.5 hours due to four emergency shutdowns, and
- A 49-hour delay in restart after a planned outage.

Not counted against the availability figure were:

- 50 hours offline due to two planned electrical outages by King County,
- 72 hours offline during digester gas testing at hot standby, and
- Various offline hours during planned trips per the test plan.

Table 4-1
Operating History Timeline for King County Demonstration

Date	Event
July 2003	FCE delivers first fuel cell stack power module to the site.
2004	
February	The original power module is shipped back to FCE as a precaution after water is found inside the stack vessel, possibly as a result of rainwater that entered the component in transit.
February-March	Balance-of-plant system testing and checkout conducted.
March 25-April 19	First phase of start-up testing with fuel cell completed. Stopped plant testing on April 19 due to repeated losses of fuel supply from the digester gas scrubbers. No backup source from Puget Sound Energy (PSE), the local gas utility, is available.
April 19-June 10	King County and PSE worked to realign gas supply so that pipeline gas provided back-up to the scrubbed digester gas. Once the facility had PSE supply in place, King County realized that PSE gas contains carbonyl sulfide (COS); FCE installed a special media to remove COS in the back-up carbon bed in the FCE natural gas treatment system. A new, permanent COS removal vessel will be installed and dedicated to PSE gas treatment in early 2005.
June 11-20	Second phase of start-up testing.
June 21-29	First phase of emissions testing on scrubbed digester gas for California Air Resources Board (CARB) certification.
June 20-July 20	Held fuel cell at 100% power while awaiting second and third phases of emissions testing.
July 21-29	Emissions tests complete; DFC1500 power plant receives CARB 07 certification.
July 30-August 1	Natural gas testing resumed.
August 2-4	Unscrubbed digester gas testing started. Determined that gas methane content changes exceeded recommended limits when the scrubbed digester gas does not meet PSE specification. This occurs when the gas cannot be sold and is put back into the unscrubbed gas supply, increasing the methane content from approximately 65% to 85%. Switched back to natural gas and await fix to methane gas content regulation.
August 5-17	Operated at 1 MW on natural gas.
August 18-20	System in hot standby. Root cause analysis conducted and corrective action due to stack pressure spike during rapid restart on August 17.
August 20-Sept. 3	Operate at 1 MW on natural gas.
September 4-12	Operate at 1 MW on unscrubbed digester gas with modified control system to respond to rapid methane content increases described above. Operated until scheduled plant two-week shutdown for electrical work for turbine generator project
Sept. 13-Oct. 23	Outage Activities: Planned Shutdown due to turbine project construction activities
Oct. 24-Nov. 22	Plant Startup and then testing of changes to digester gas to natural gas fuel-switching logic.
November 23-30	Testing takes a break for Thanksgiving, plant operates on natural gas at 1 MW.
December 1-16	Testing of digester gas to natural gas fuel-switching logic resumes and completes.
December 16-31	Plant operating on digester gas at 1 MW.

Electric Output

Total electrical power supplied by the fuel cell system to the King County wastewater treatment plant as of December 31, 2004, was 2,390 MWh.

Additional Data

Additional operating data for the period of June 14, 2004 through December 31, 2004 are tabulated below. A more complete report synthesizing all the results is planned for publication at a future date.

Table 4-2
Additional Operation Data (June 14, 2004 through December 31, 2004)

	NG and DG Combined	Natural Gas	Digester Gas (unscrubbed)
Availability	91.6%	93.8 %	79.3 %
Opportunity (hours available in test period)	2567 hrs	2178 hrs	389 hrs
Unexcused Outage Time	216 hrs	135 hrs	81 hrs
Power Output	2,390 MWh	2,077 MWh *	313 MWh *
Efficiency (LLH)		44%	45%

*** These output data are estimates that assume output is proportional to operating hours.**

Power plant availability during digester gas operation was affected by logic changes and verification needed to address the effects of the fuel composition variation. The efficiency of the power plant on digester gas is not yet fully optimized. The plant was not designed to accommodate large variations in methane content. However, the project met the overall efficiency goals for the demonstration unit.

Emissions

Exhaust emissions from the DFC1500 Fuel Cell Power Plant were analyzed by a professional emissions testing firm in July 2004. Exhaust stack emissions were analyzed for concentrations of nitrogen oxides, carbon monoxide and non-methane hydrocarbons. Emissions were analyzed at three separate power levels (p.l.): nominally 50%, 75% and 100% of rated power. Three separate emissions test runs of one-hour duration were performed at each power level. The average results of the three runs for each pollutant and for each power level are presented in Table 4-3. As can be seen, the emission levels are negligible, as expected.

Table 4-3
Measured Average Stack Concentrations (dry basis) at indicated power levels

	Concentration		
Pollutant	**50%**	**75%**	**100%**
NOx (ppm)	1.6	0.2	0.2
CO (ppm)	5.3	4.5	6.7
NMHC (ppm)	0.5	0.2	0.6

Exhaust stack gas volumetric flow and moisture content were also measured during emissions testing, as was the actual net power electrical power output of the plant. Using these data, together with the stack gas measured pollutant concentrations, power-normalized pollutant emissions rates (in terms of lbs/MW-hr) were calculated. These data were reported to the California Air Resources Board (CARB) Distributed Generation Program to obtain certification of the DFC1500 under the 2007 standards (CCR 94200-94214). The CARB certification program uses a weighting formula of power-normalized emission rates at different power levels to evaluate conformance with their standards. The power-normalized pollutant emissions rates and the CARB Distributed Generation Program Certification Standards are provided in Table 4-4. As can be seen, the DFC1500 fuel cell power plant easily passed the CARB-2007 Distributed Generation Program Certification Standards.

Table 4-4
CARB Certification Requirements and Ratings *

	lb/MW-hr		
	DFC1500	**CARB-DG Requirement**	
Pollutant	July-04	2003	2007
NOx (as NO_2)	0.017	0.5	0.07
CO	0.10	6	0.1
NMHC (as C)	0.003	1	0.02

* (Power normalized emissions weighted @ (0.2 x 50% p.l.) + (0.5 x 50% p.l.) + (0.3 x 100% p.l.)

5
CONCLUSIONS

5.1 Lessons Learned

As the King County Fuel Cell Demonstration Project has only recently begun, there is little operational or performance data available. The 1-MW fuel cell power plant supplied by FuelCell Energy for digester gas application is a first-of-a-kind design. As a result, some problems were encountered which extended the period for completion. Feedback from the construction and commissioning of the power plant are being utilized to improve the design for future units. Operational data to date indicate favorable results on both natural gas and digester gas. The fuel cell power plant and its ancillary components do operate and produce consistent power, with low emissions, provided a reliable gas supply is available. Digester gas contains approximately 60% methane, as compared to natural gas that is more than 95% methane. However, no derating of the DFC1500 power output was required for digester gas application.

Gas Supply

One important challenge has been the supply and quality of fuel at the facility, a problem exacerbated by King County's unique arrangement with its local gas utility. As discussed in Chapter 3, much time and effort has been spent trying to mitigate the effect of loss of scrubbed digester gas and the impact that a divert to the ADG header has on raw digester gas composition. FCE has implemented a solution that automatically switches over to natural gas when digester gas quality is not adequate. King County will be routing a new pipeline directly from the digesters instead of the ADG header to ensure constant methane content in the unscrubbed digester gas.

Either solution would only be temporary (until 2005), because when the planned turbine generation system is in place King County will no longer sell the scrubbed gas to Puget Sound Energy (PSE). Afterward, divert events in which scrubbed gas is recycled back to the ADG header should no longer occur.

In addition to this internal fuel supply challenge, King County and FCE were also concerned about concentrations of carbonyl sulfide (COS) in the natural gas that it receives from PSE. COS occurs naturally in natural gas and is uncommonly concentrated in gas from Canada, the source of the PSE gas sent to the South Treatment Plant. As discussed previously, COS can "poison" a fuel cell stack and severely degrade performance. As a result, King County is implementing an additional cold gas desulfurizer vessel for the COS treatment. While the new vessel was being engineered and constructed, one of the FCE gas treatment system redundant activated carbon beds was emptied and copper and aluminum oxide added. This is a temporary measure to ensure that no COS reaches the fuel cell.

Interconnection

Resolving interconnection issues with Puget Sound Energy (PSE) was challenging and time-consuming. The design team began discussions with PSE early in the project, which was essential. It is possible that the long negotiation experienced with the interconnect agreement is not unique to fuel cells, but an issue that all distributed generation technology may face with local utilities.

The fuel cell is not isolated from the PSE grid, requiring coordination with the utility for interconnect. The PSE grid provides a voltage and frequency reference point that is required by the fuel cell when operating in parallel to the grid. The local utility and national interconnection standards require generators operating in parallel to take themselves off-line when voltage and frequency deviations in the grid are observed by the generator. The fuel cell electrical balance of plant senses when variations in voltage and frequency in the grid exceed certain thresholds and stops generating power to comply with the utility's safety and interconnection rules.

PSE's interconnect also was required for revenue collection. As various demands are placed upon the PSE grid from end users, PSE must ensure there is enough power for all customers. When the fuel cell is on-line, rates are different than when the fuel cell is off-line. This enables PSE to keep up with the power demand. The interconnect agreement is the vehicle to establish different rates through revenue class metering.

In addition to PSE, the local electrical inspector from the City of Renton was unfamiliar with fuel cells. He had knowledge of the National Electrical Code (NEC) that applies specifically to residential fuel cells, not the class of the Direct FuelCell installed. The uniqueness of the project prolonged the inspection process.

Other states such as California have instituted standard interconnection standards for on-site generation equipment like fuel cells, whereby manufacturers can pre-certify their equipment against these standards and significantly simplify the interconnection process. Such policies currently vary state to state.

King County's experience points to the larger need for education and training, even among industry professionals. Inexperience and discomfort with unfamiliar technology is a barrier hindering the deployment of distributed resource that will be confronted project by project, jurisdiction by jurisdiction, until the technology becomes more common. Early and frequent communication with local inspectors and utilities can help smooth the process as the permitting and interconnection agreements may be complex and/or cumbersome.

Other Challenges

The project team reported unanticipated problems, including the previously mentioned presence of water in the first fuel cell stack power module delivered in July 2003, which necessitated its shipment back to FCE and subsequent replacement as a precaution.

As expected, lessons learned were not restricted to the fuel cell power plant; issues concerning the installation and engineering of the heat recovery system were also experienced. As stated, these and other issues are typical and expected when installing and starting power generation projects. Other start-up and commissioning challenges included the addition of a water booster pump that was required to provide water at the pressure required (by specification) by the FCE water treatment system and the new COS removal vessel to meet the FCE natural gas quality specification.

Despite the challenges noted above relating to the design, fabrication and installation of the power plant, each of the project participants have responded very well in an effort to make the installation at this site a success.

Conclusion

The King County Fuel Cell Demonstration project has benefited from positive experiences. For example, the modules supplied by FCE were installed and made ready for operation very quickly. Once the typical start-up hurdles were passed, the fuel cell operated well and without major issues. Power production is constant and power quality is high. The output of the fuel cell did not need to be derated when operating on digester gas, which would have been required with some other fuel cell technologies.

Classroom training of mechanical and electrical maintenance workers was completed in December 2004. Classroom training of 10 operators was completed in December as well. These operators are expected to complete their hands-on training by mid-February 2005. As of January 27, 2005 all preventative maintenance activities are being performed by King County, and King County operators are responding to alarms.

The fuel switch logic addition has proven to be very successful and will have a positive impact on Digester Gas power availability and overall plant performance.

System efficiency to date on natural gas is 44% and on digester gas is 45%. Overall availability as of December 31, 2004 was 91% and increasing.

Emissions testing resulted in meeting the CARB 07 requirements and subsequently becoming the first and only 1-MW fuel cell power plant to be certified as of the date of this report.

FCE has responded quickly to repair field issues and get the system up and running. From this point forward, the project team will be able to optimize the fuel cell to assess the bookends are for operation. Now that the stack is operating at steady–state, the operating parameters will be adjusted and refined.

Permitting for the project was easy because of the ultra-clean characteristics of the fuel cell. Effort was required for electrical inspection due to the uniqueness of the equipment.

A
PROJECT PLAN AND GOALS

Monitoring Program

King County, FCE, and their project partners are monitoring various areas of fuel cell operation throughout the two-year demonstration period. Data continues to be collected and analyzed to help determine the feasibility of undertaking similar efforts in the future. These data will also be reviewed periodically by the Peer Review Team throughout the demonstration period so that the testing program can be altered and enhanced as appropriate. Data gathered from instruments integrated into the fuel cell systems are being augmented by manual spot checks conducted quarterly with more accurate instruments. Data gathered include:

- Gas (hourly):
  - Flow
  - Pressure
  - Availability
  - Natural gas used vs. digester gas used.
- Fuel Cell Stack (daily):
  - Run time
  - Efficiency
  - Stack integrity
  - Availability to process digester gas and natural gas.
- Energy (daily):
  - Quantity produced as ac
  - Parasitic energy use (gas pretreatment, water conditioning, blowers, reformer, etc.)
- Heat Recovery System (hourly):
  - Temperature of water in and out (Btu recovered)
- Noise (quarterly):
  - dBA levels in the vicinity of the fuel cell
- Radio Frequencies (quarterly):

  - Ability to get reception on walkie-talkie radios, without tripping, outside the perimeter of the fuel cell.
- System Energy Balances (quarterly):
- Annual Costs (quarterly):
  - O&M activities performed
  - Spare parts and maintenance
  - Electricity
  - Water
  - Anode gas
- Remote Operation (monthly):
  - Ability to monitor and operate remotely from South Treatment Plant
  - Ability to monitor and operate remotely from FCE offices in Connecticut
  - Functionality of modem for remote operations
  - Functionality of telephone pager for broadcasting alarms.
- At the end of the project:
  - Solid waste disposal and media replacement costs (e.g., catalysts, fuel cell stack, SulfaTreat, carbon).

B
PROJECT STAFF AND ADVISORS

Operations and Testing Staff

Name	Role	Responsibility
Greg Bush	King County Project Manager	Oversight of FCE and CH2M Hill contracts
Eddie Tate	King County Construction Manager	Oversight of Hawk Construction
Carl Mack	King County Project Engineer	Oversight of FCE start-up and commissioning
Mike Fisher	King County South Treatment Plant (STP) Superintendent	Plant superintendent
Rick Butler	King County STP Process Control	Supervisor of process control
Carol Nelson	King County STP Process Control	Main contact for fuel cell operations
Frank Stratton	King County STP Maintenance	Main contact for fuel cell maintenance
Tommy Edwards	King County Electrical Inspector	Electrical inspector
Jim Faccone	King County Health and Safety	Assist in developing safe operation and testing procedures
David Hennessy	FCE Project Manager	Oversight of FCE team
Eleanor Allen	Consultant Team Project Manager	Oversight of CH2M HILL/Brown and Caldwell team
Jaimie Hennessy	Design Manager	Point person for design-related issues
Gary Anderson	Electrical Engineer	Assist in interconnect agreement and electrical issues
Mark Corsentino	Project Engineer	Assist King County in gathering and analyzing data
Dan Beachy	FCE MW Field Supervisor	Oversight of commissioning, testing and operations
Jamie Mordarski	FCE MW Field Service Team Lead	Onsite supervision during commissioning testing and operations
Winston Spencer	FCE MW Field Service Team Lead	Onsite supervision during commissioning testing and operations

Peer Review Team

The Peer Review Team consists of industry experts who meet semi-annually to review data and test results, and advise on any changes to the testing program.

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